The Decline of the Steller Sea Lion in Alaskan Waters: Untangling Food Webs and Fishing Nets

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The study was overseen by the Ocean Studies Board and the Polar Research Board of the National Research Council

The study was sponsored by the North Pacific Fishery Management Council

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Genesis of Study

- **Nov. 2000:** NMFS concludes that Alaska groundfish fishery posed a threat to the recovery of SSLs
- **Dec. 2000:** Congressional Record (House H12260), "The North Pacific Fishery Management Council … shall utilize the expertise of the National Academy of Sciences to conduct an independent scientific review of the November 30, 2000 Biological Opinion … of Alaska groundfish fisheries …, its underlying hypothesis … The National Academy of Sciences is requested to give its highest priority to this review."

Why the Academies?

- Independence
- Balance
- Objectivity
- Quality

Each activity is conducted by a group of volunteer experts selected for that specific task, with oversight from the Ocean Studies Board and The Academies.

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Study Timeframe

- **April 1, 2001:** start date for NRC study
- **December 4, 2002:** Executive summary issued
- **January 13, 2003:** Prepublication of report available
- **March 2003:** Final publication available

Statement of Task

This study will examine interactions between Alaska groundfish fisheries and Steller sea lions (*Eumetopias jubatus,* SSLs) and the role of these fisheries in the evolving status of the SSL population. The focus of the study will be:

- The status of current knowledge about the decline of the SSL population in the Bering Sea and Gulf of Alaska ecosystems,
- The relative importance of food competition and other possible causes of SSL population decline and impediments to SSL recovery,

Statement of Task (continued)

- The critical information gaps in understanding the interactions between SSLs and Alaska fisheries,
- The type of research programs needed to identify and assess potential human and natural causes of SSL decline, and
- The components of an effective SSL monitoring program, with yardsticks for evaluating the efficacy of various management approaches.

Approach

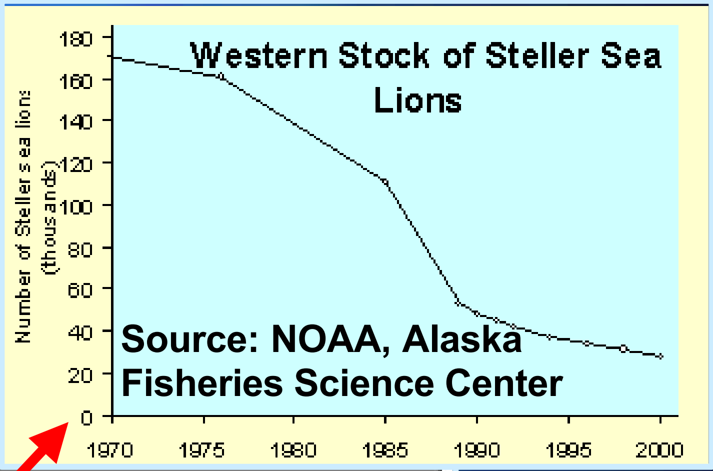
- **Information gathering during public meetings:**
  - **Aug. 22-23, 2001, Seattle:** NPFMC, NMFS, NMML
  - **Oct. 29-30, 2001, Anchorage:** Native associations, fishing industry, environmental organizations, consultants, ADF&G, and academia
  - **Dec. 10-11, 2001, Seattle:** academia, MMC, PWSSC, USFWS, NMFS, NMML, ADF&G, consultants
- **Review:** scientific publications and results from ongoing research projects

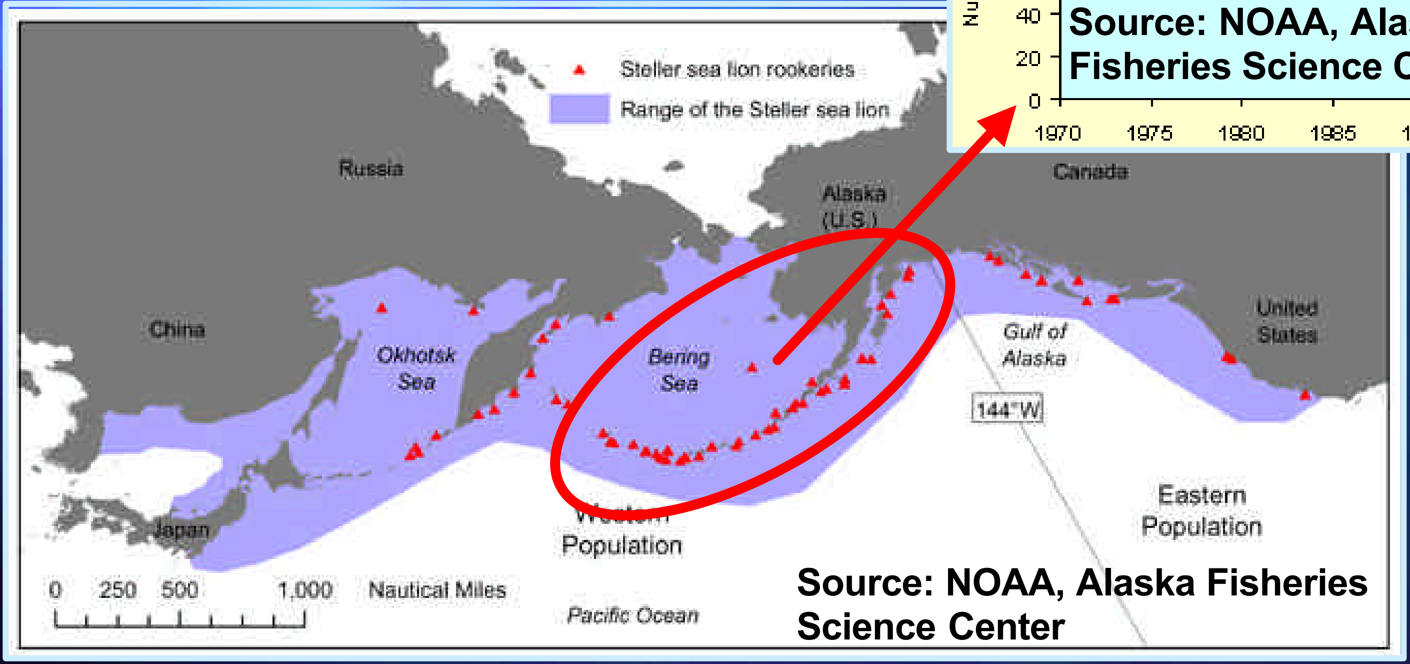
Approach (continued)

- New analyses:
  - Estimate groundfish biomass available per SSL based on NMFS fish and SSL abundance estimates
  - Population modeling to estimate unexplained mortality based York’s age-structured model
  - Ecosystem modeling of eastern Bering Sea based on Ecopath/Ecosim models of Walters et al. (1997, 1999) and Trites et al. (1999)
  - Qualitative response variable analysis based on Bowen et al. (2001)

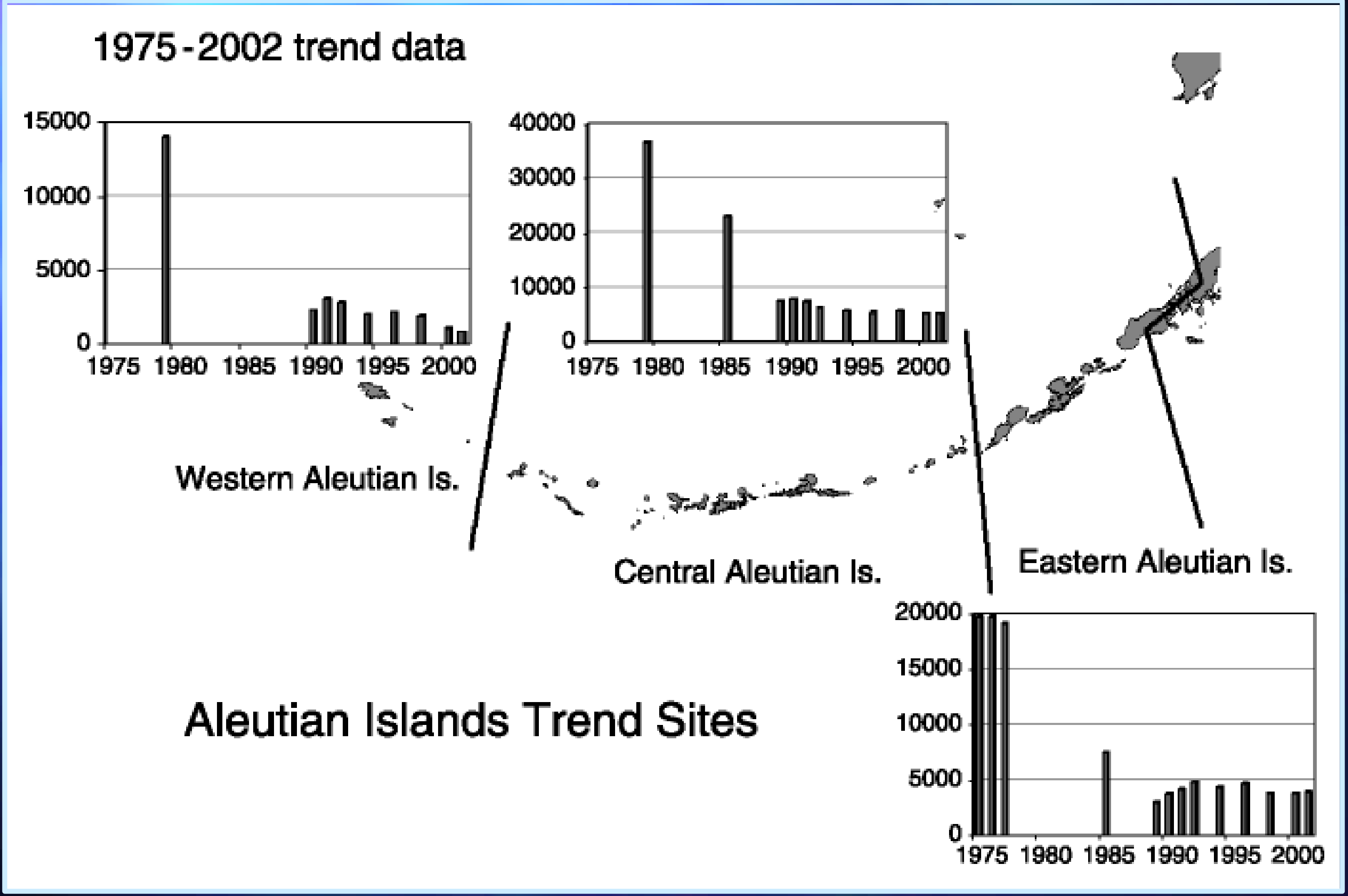
What is the status of current knowledge about the decline?

- The western stock of SSLs has declined more than 80% since the 1970s
- Decline was steepest in the 1970s and 1980s.

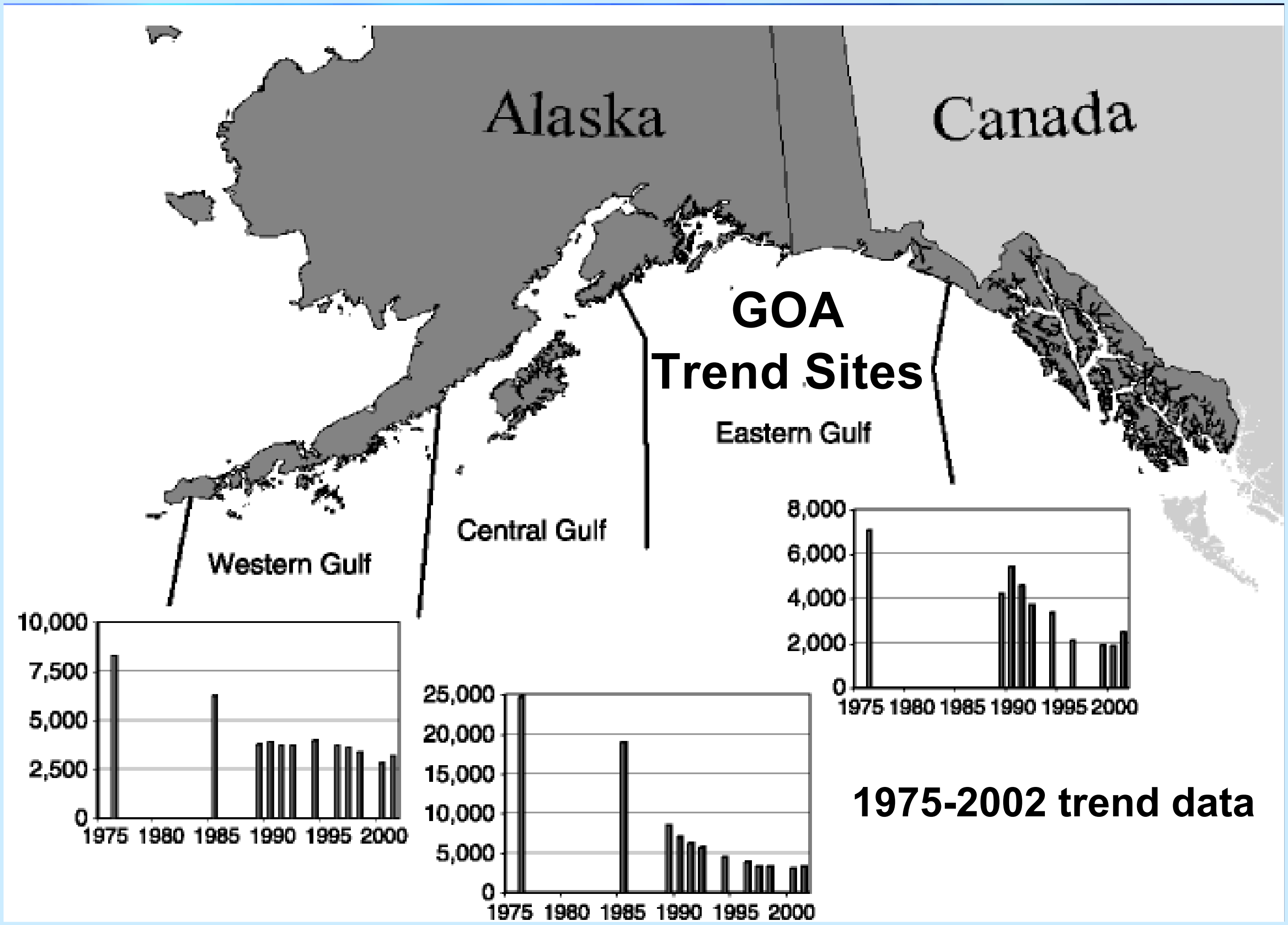




Spatio-temporal Patterns of Decline



Spatio-temporal Patterns of Decline



What is the importance of food competition and other causes in the decline?

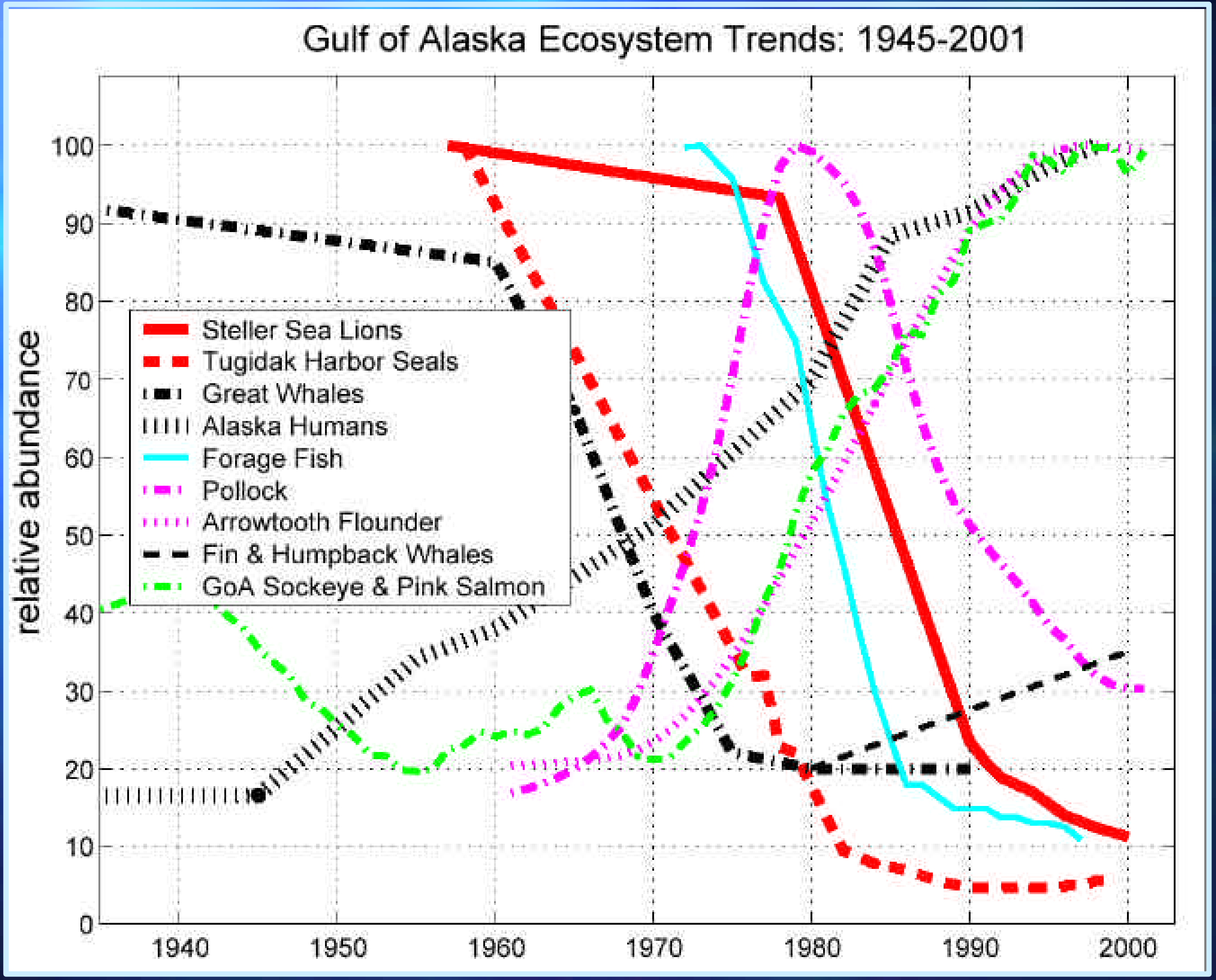
Most marine mammal declines due to humans:

- Commercial harvests for fur, meat, oil
- Fishery interactions – disturbance/incidental catch
- Predator control programs

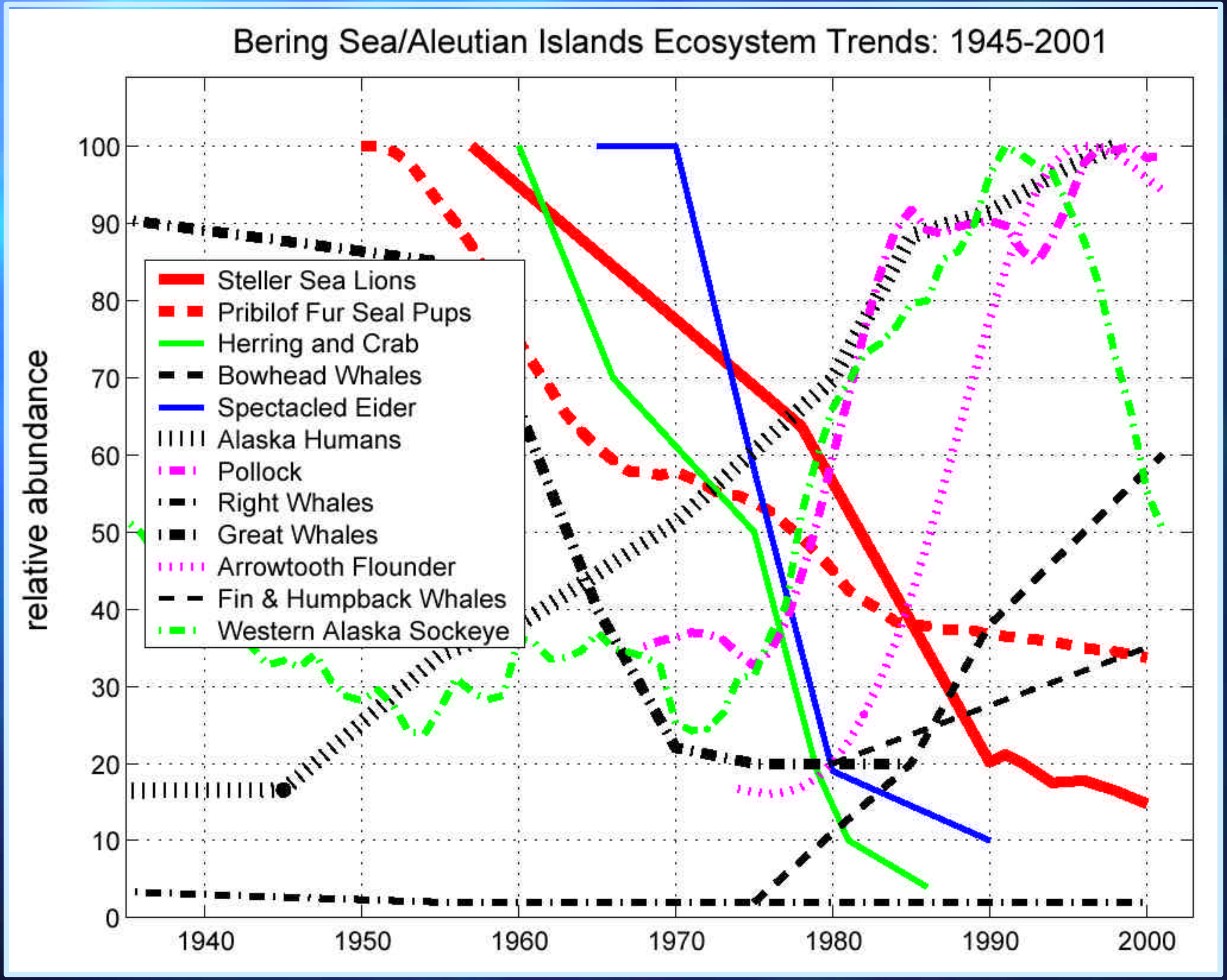
Case of SSLs is not straightforward:

- No commercial harvests since 1972
- Reported takes of SSLs by fisheries are small
- Few baseline data to compare healthy, pre-1975 population with current, depleted population
- Shifts in marine species abundance in 1970s-1980s attributed to commercial harvests and climate

The Complexities of Change



The Complexities of Change



Hypotheses about SSL Decline

Bottom-up hypotheses:

- Large-scale fishery removals have reduced the availability or quality of prey species,
- A climate regime shift in the late 1970s has changed the abundance or distribution of prey species,
- Non-lethal disease has reduced the foraging efficiency of sea lions, and
- Pollutants concentrated through the food web has contaminated fish eaten by sea lions, possibly reducing their fecundity or increasing mortality.

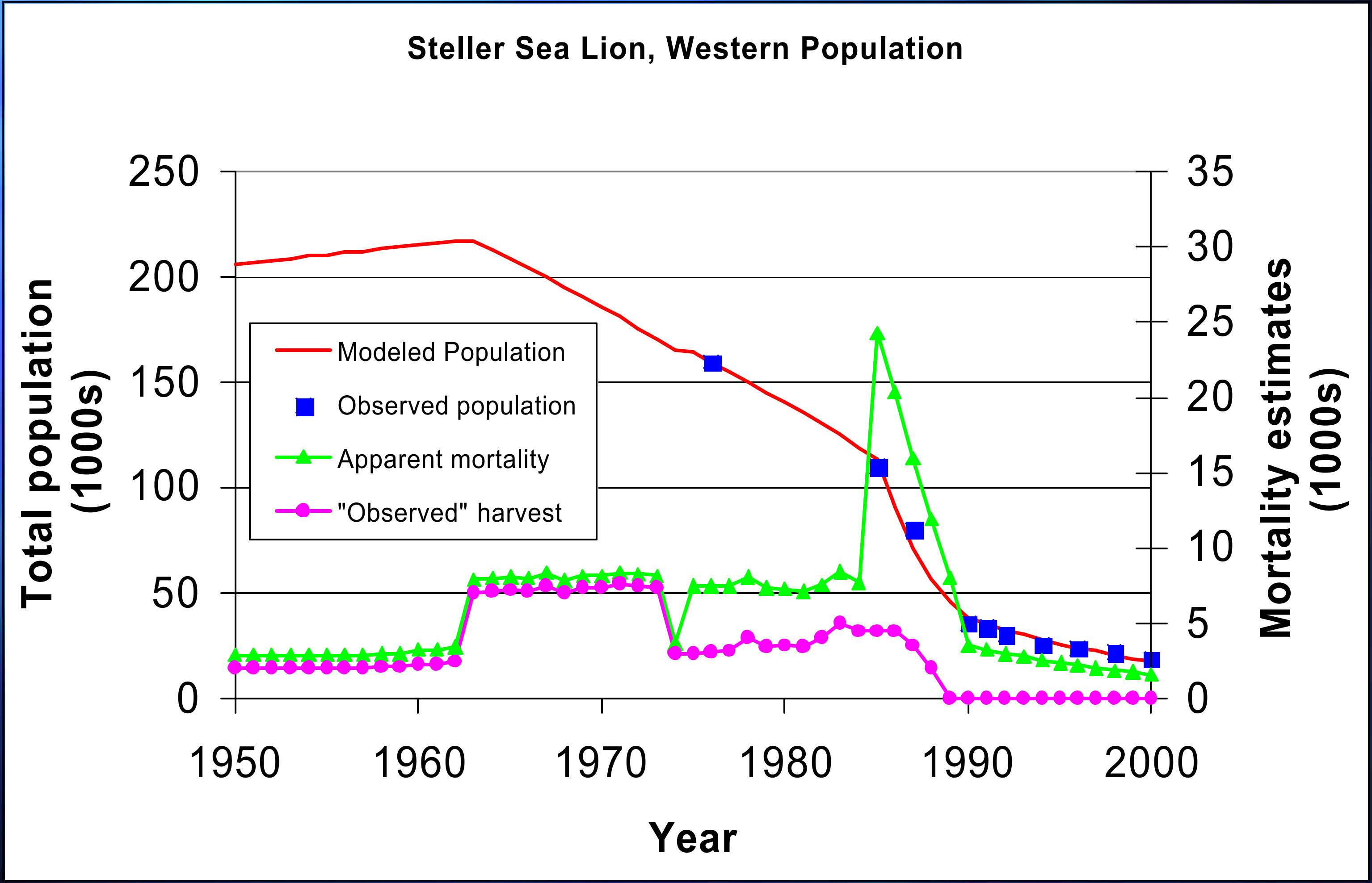
Hypotheses about SSL Decline

Top-down hypotheses:

- Predators such as killer whales (or possibly sharks) have switched their prey preference to sea lions,
- Incidental take of sea lions through capture or entanglement in fishing gear has increased as a result of the expansion of commercial fisheries,
- Takes of sea lions in the subsistence harvest have been higher than estimated,
- Shooting of sea lions has been underestimated in the past and present, and
- Pollution or disease has increased mortality independent of effects on nutrition.

Clues from Population Models

Application of York (2002) model:



Clues from Population Models

- Unexplained mortality peaked at 20,000-25,000 animals per year in mid-1980s
- Total estimated mortality from groundfish takes, subsistence, shooting, predation is about 4,500 per year in mid 1980s
- The losses are too large to have only involved pups and yearlings
- These losses have been widely claimed to have been due to nutritional stress, but killings by humans and natural predators are based on limited data

Clues from Ecosystem Models

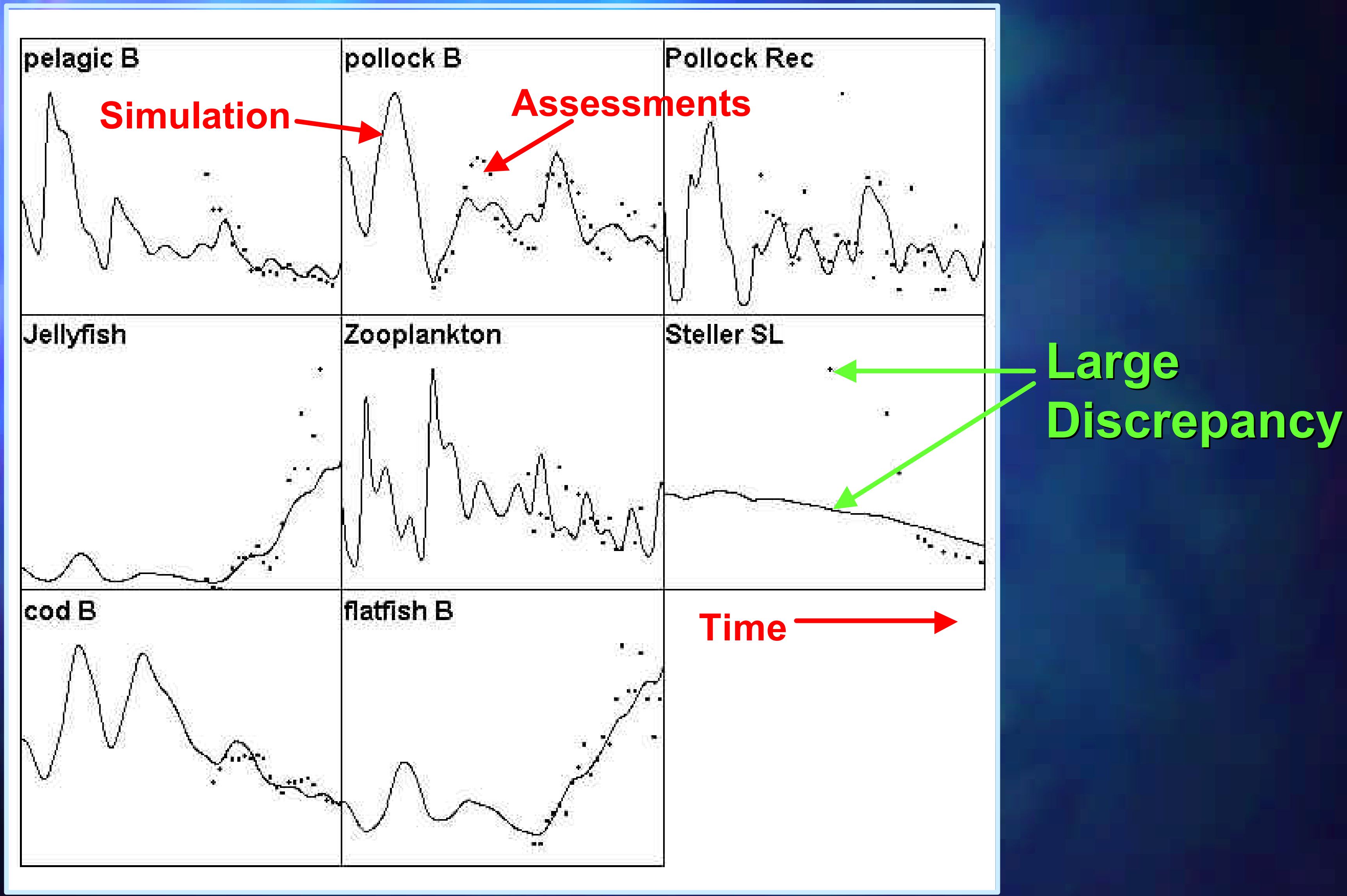
Strategy

- An Ecosym/Ecopath model was developed for eastern Bering Sea during 1950-2000 based on Trites et al. (1999)
- See NAS (2003) for details
- Modeling is used to identify plausible scenarios

Some Results

- Reasonable fits to trends in many species groups
- Anomalies best explained by climate regime shifts
- Little variation is explained by historical fishing rates alone
- Much of the good fit is associated with cascade effects after the cessation of whaling

Clues from Ecosystem Models



Clues from Ecosystem Models

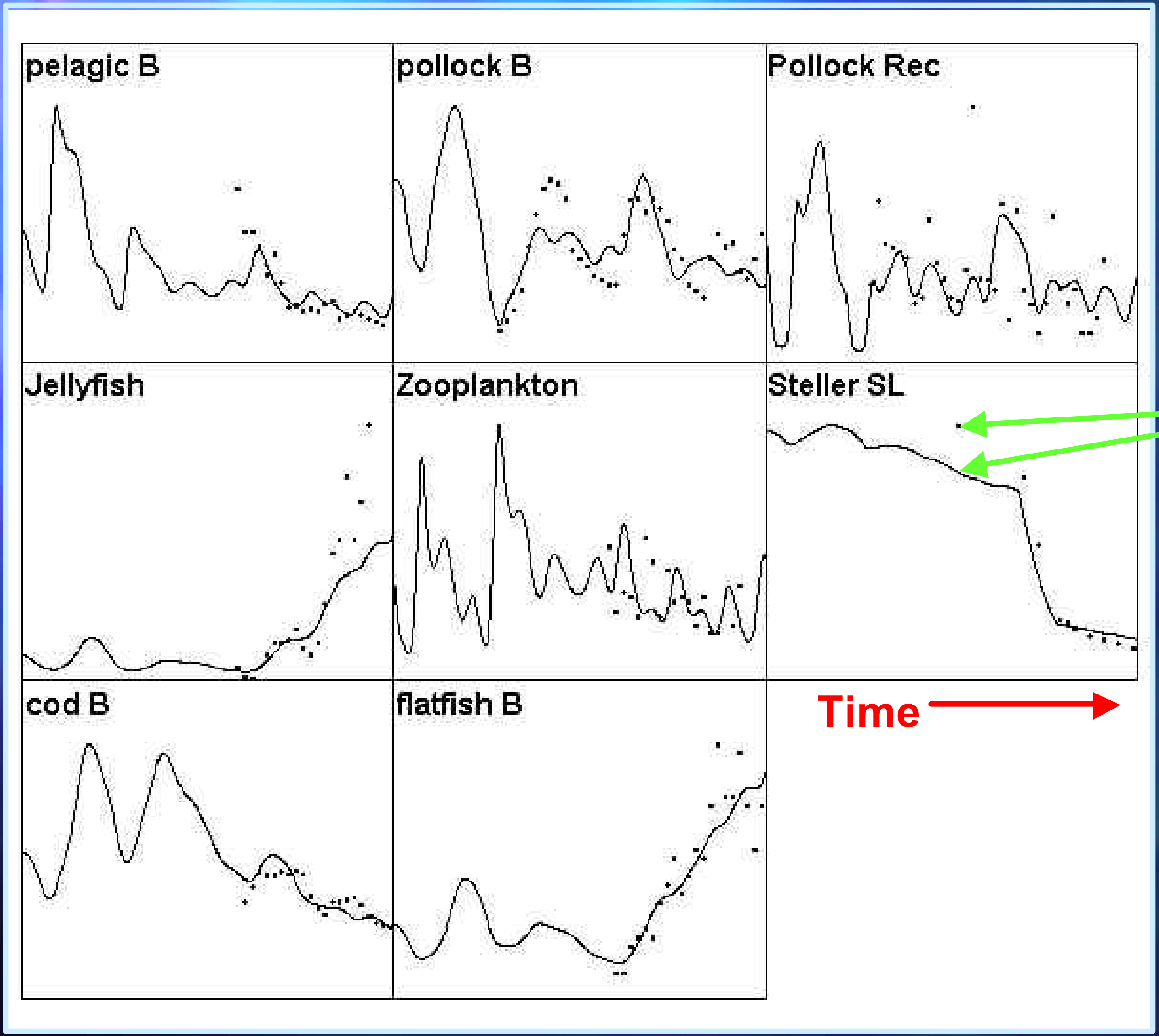
Scenario

- Reduced sperm whales led to increased squid
- Squid increased predation on small pelagics
- Reduced small pelagics led to start of SSL decline
- More zooplankton led to increases in jellyfish
- Herring fisheries hastened herring and SSL declines
- Fewer herring led to increases in other pelagics
- More pelagics led to an increase in benthic piscivores, such as arrowtooth flounder

Conclusion

- No parameter combination involving only trophics and fishing can match the steep SSL decline
- Scenarios assuming more SSL culling by fisheries improves fit to SSL observations in 1980s

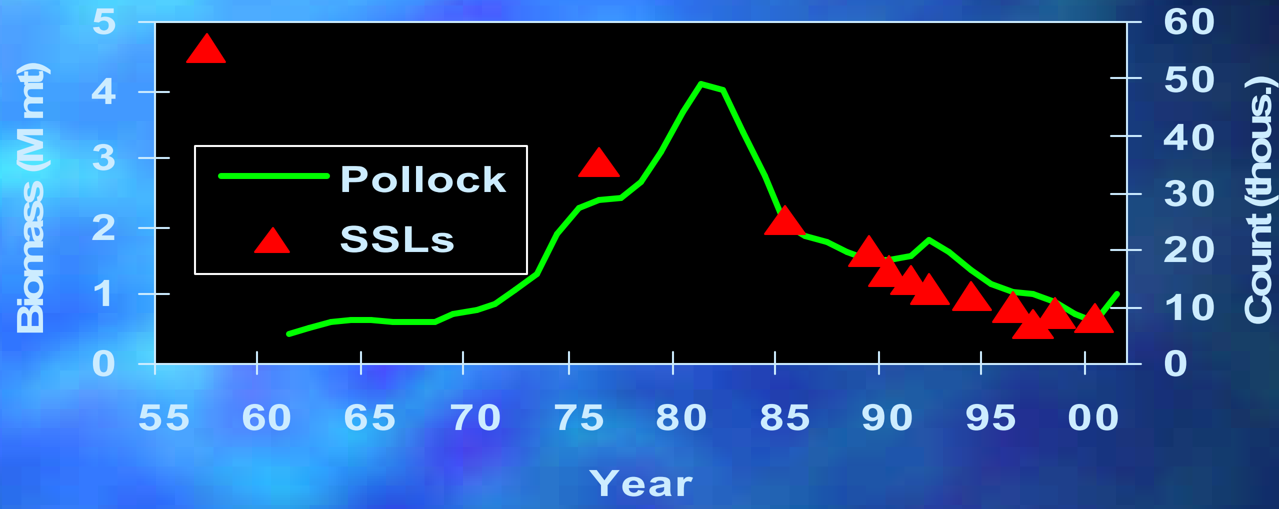
Clues from Ecosystem Models

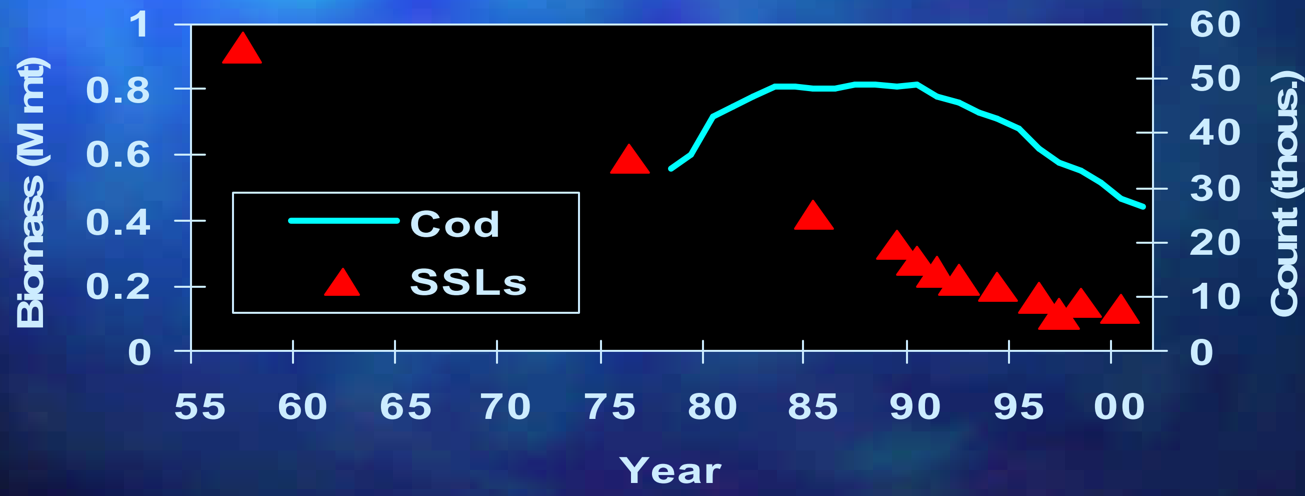


Less Discrepancy

Evaluating the Bottom-up Hypotheses

Fishery removal hypothesis – Gulf of Alaska:





Evaluating the Bottom-up Hypotheses

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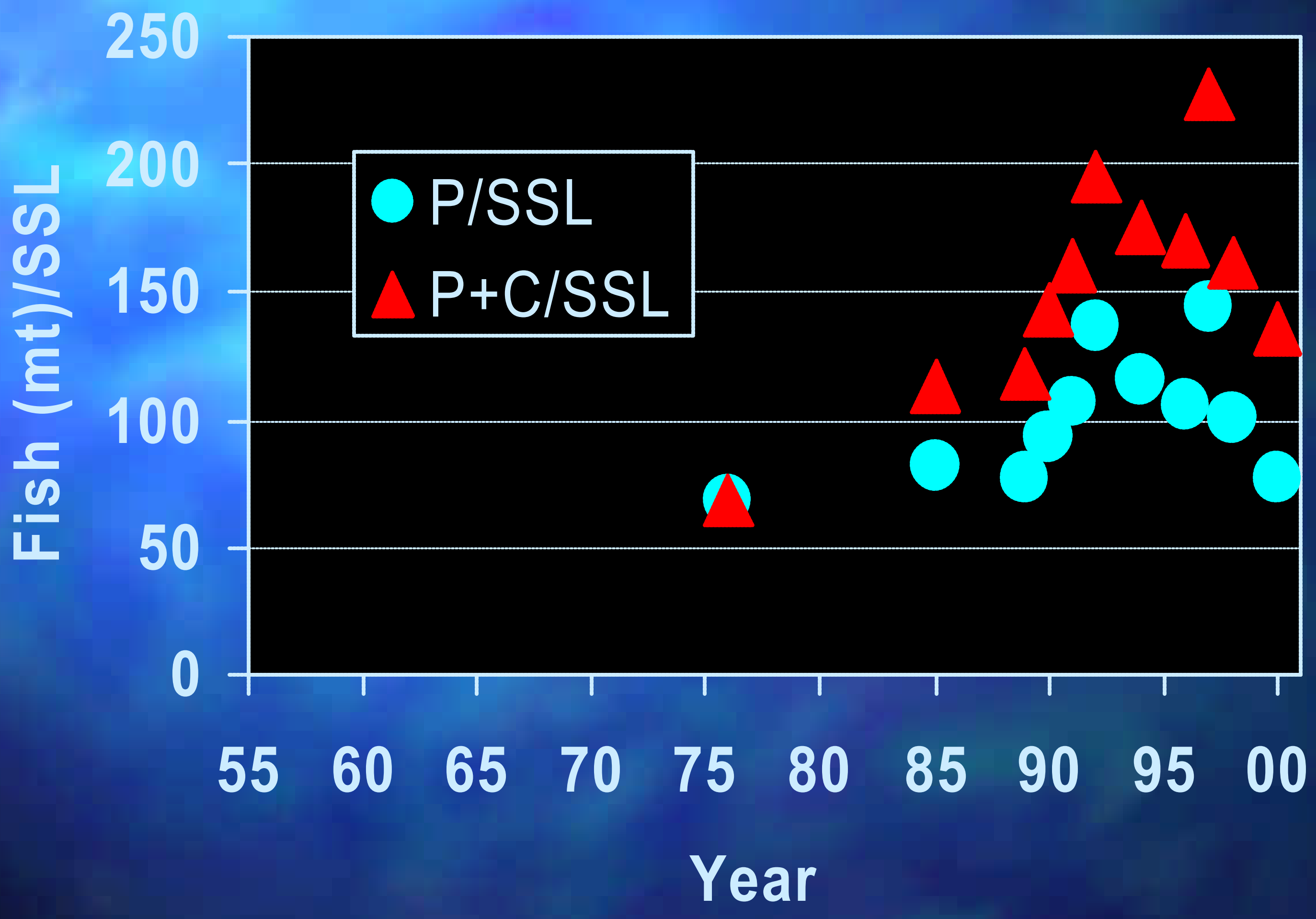
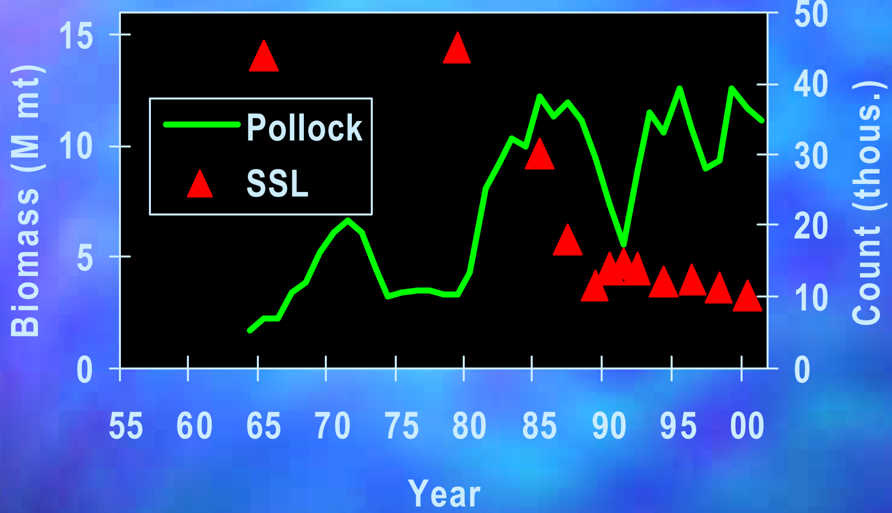
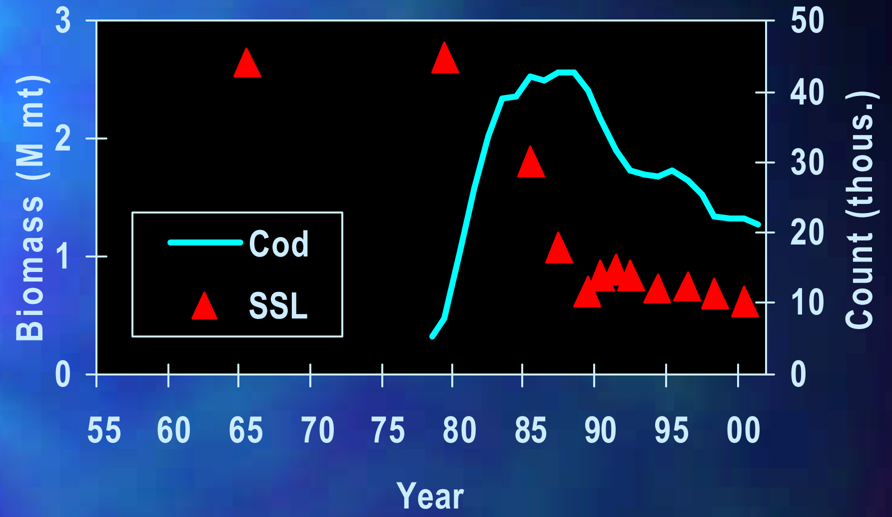
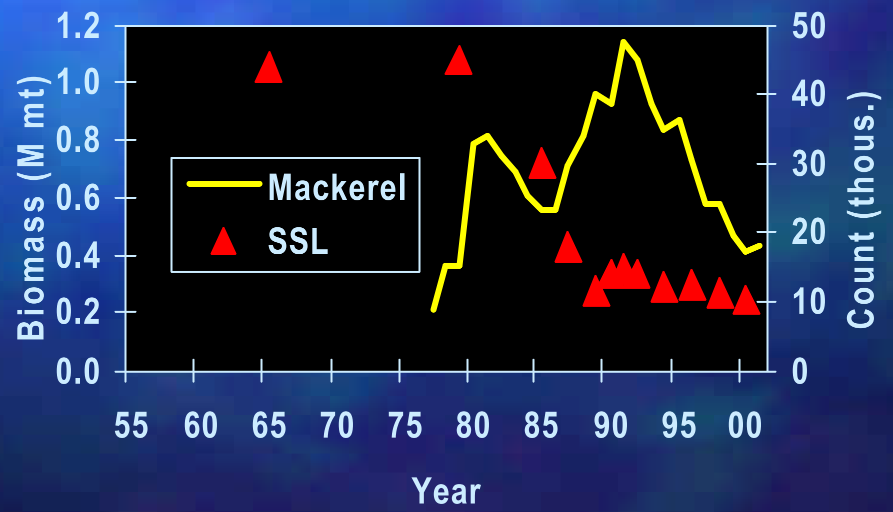


Evaluating the Bottom-up Hypotheses

Fishery removal hypothesis – Bering Sea:







Evaluating the Bottom-up Hypotheses

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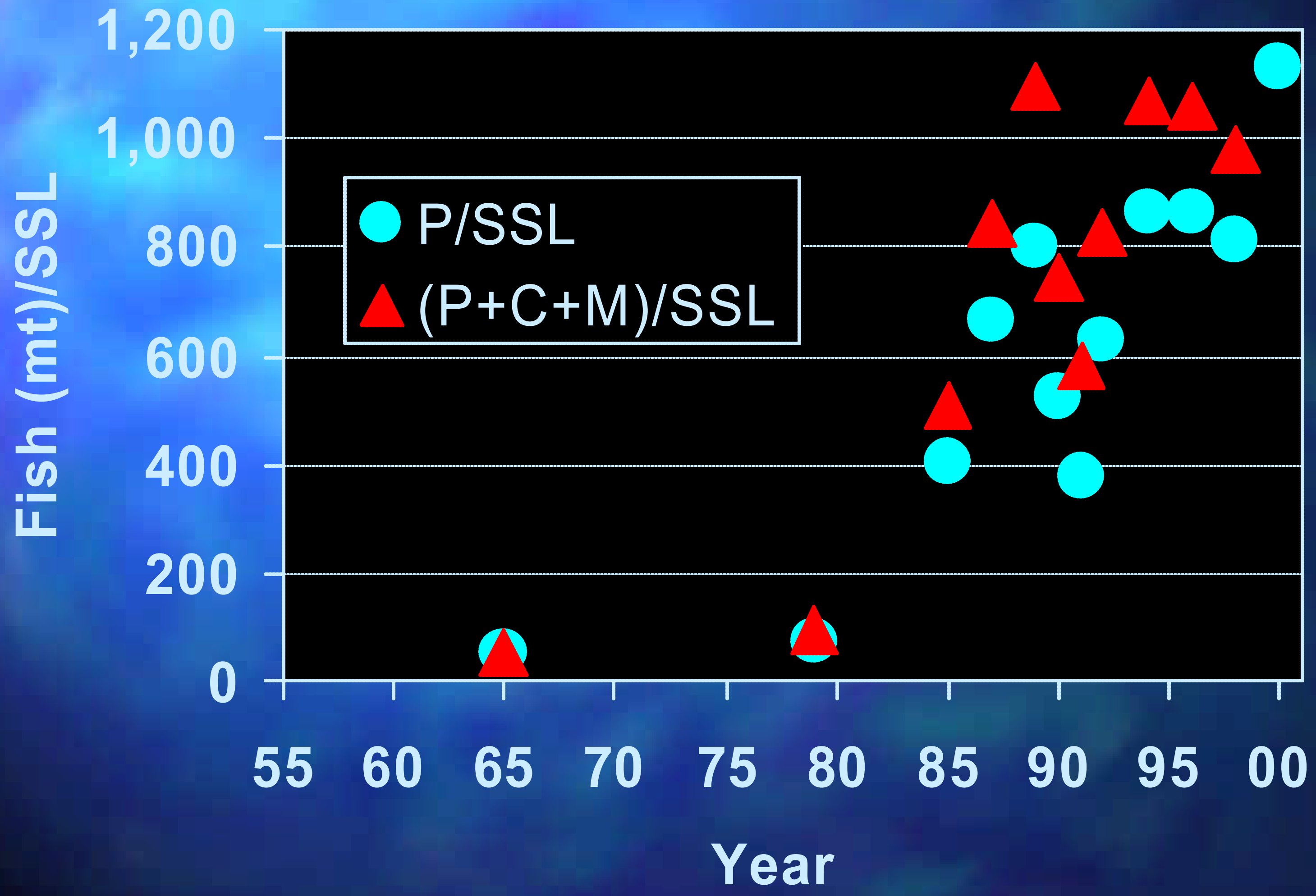


Evaluating the Bottom-up Hypotheses

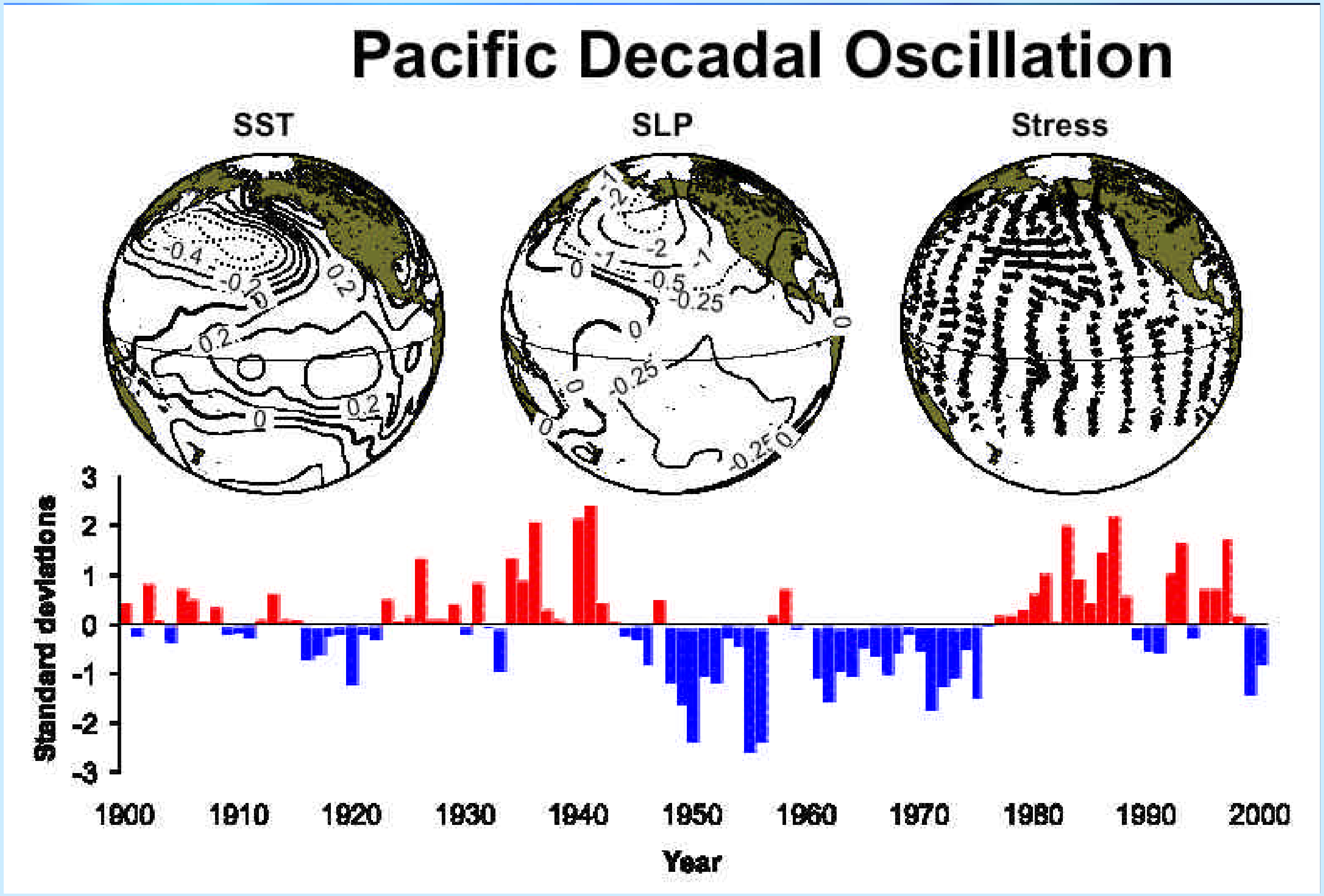
Fishery removal hypothesis:

- Hypothesis not supported by general considerations of fish biomass and sea lion abundance
- Localized depletion remains an open question:
  - Fritz (1999) found evidence for localized depletion of Atka mackerel in 1990s
  - Wilson et al. (2002) found no evidence for localized depletion of pollock in Kodiak in 2000-2001

➔ More research on reactions of fish schools to fishing, seasonal fish movements, sea lion foraging behavior are needed

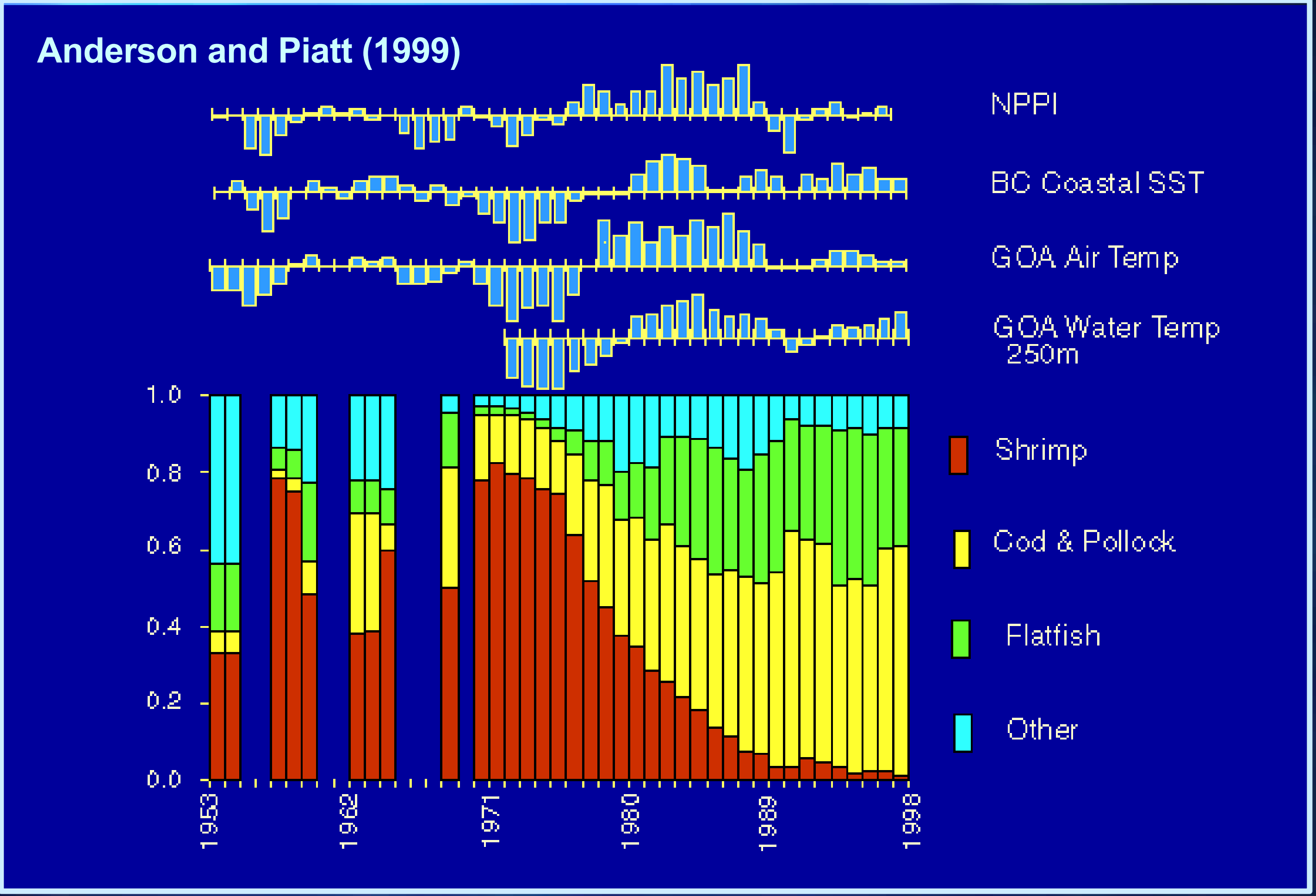
Evaluating the Bottom-up Hypotheses

Climate regime shift hypothesis



Evaluating the Bottom-up Hypotheses

Climate regime shift hypothesis



Testing this hypothesis requires a "wait and see" approach

Evaluating the Top-down Hypotheses

Predation:

• Salmon sharks – no records of SSL attacks

• Sleeper sharks – occasional remains of marine mammals, but no documented SSLs

• Killer whales – documented attacks; beached killer whale contained tags of 14 SSLs; increased SSL predation could fit in with cascade hypothesis

Photo: NOAA, Alaska Fishery Science Center

Photo: Betty Sederquist http://www.sederquist.com

Evaluating the Top-down Hypotheses

Incidental take:

- Low rates of entanglement reported
- Thousands of takes in JV pollock trawl fishery in Shelikof Strait in mid-1980s
- Estimated takes by fisheries do not account for SSL declines, but observations are limited to observed vessels and voluntary reports

Subsistence harvest:

- Russian missionaries reported ~2,000 SSLs harvested annually on St. George Island in the 1830s
- One community on Kodiak Island harvested a reported high of 178 animals in 1983
- In 1995, total takes were 171, of which 43 were lost

Evaluating the Top-down Hypotheses

Shooting:

- SSLs shot in 1940s by PBYs
- Salmon trap operators killed 816 SSLs in spring 1954
- Predator control program in 1950s-1960s (all pups shot on Amatuli Island on 2 occasions)
- Experimental harvest of 45,178 SSL pups in 1963-1972
- Shooting weapons became illegal in 1990

Disease and toxins:

- SSLs have antibodies to agents that could decrease survival and reproduction, but no evidence of epidemic
- Unlikely that contaminants are causing direct SSL mortality, but more research on subtle effects needed

Response Variable Analysis

The committee modified and extended the Bowen et al. (2001) approach by:

- Organize hypotheses into top-down and bottom-up forcing mechanisms
- Derive expected directions of change from the IS IT FOOD? Conference (1993) similar to Eberhardt's (1977) approach for marine mammals
- Compared recent (1990s) available observations with expected changes
- Evaluated the weight of evidence for each hypothesis

Response Variable Analysis

- Observed characteristics of SSL biology and behavior should be different under the two categories of hypotheses:
  - **bottom-up hypotheses** predict increased mortality through reduction in physical condition (changes in physiology, reproductive success, foraging behavior)
  - **top-down hypotheses** predict no loss in individual fitness, but require increased activity by predators, people, or pathogens
- Data can be sorted temporally and geographically
  - threats during 1985-1989 had lessened in 1990s
  - threats greater in western than eastern stock

Response Variable Analysis

Forcing Direction	Bottom-up		Top-down					Uncertain
Correlate/Response Variable	FR	CE	PRED	DT	SH	IT/ENT	D	PO
Pups								
Birth mass (1)	L/H*	L/H*	H*/H*	H*/H*	H*/H*	H*/H*	U/H*	U/H*
Pup growth rate (1,2[a], 3[a])	L/H	L/H	H*/H	H*/H	H*/H	H*/H	U/H	U/H
Adult female								
Body condition (4,5,6)	L/H	L/H	H*/H*	H*/H	H*/H	H*/H	L/H	L/H
Foraging trip duration (7,8)	H/L	H/L	L/L	L*/L	L*/L	L*/L	L/L	L/L
Dive depth (9)	H/L	H/L	L/L	L*/L	L*/L	L*/L	L/L	L/L
Field metabolic rate (9)	H/L	H/L	L*/L	L*/L	L*/L	L*/L	L/L	L/L
General								
Foraging range (10)	H/L	H/L	L/L	L/L	L/L	L/L	L/L	L/L
Beach strandings (11)	H/L	H/L	L/L	U/L	L/L	L/L	H/L	H/L
Other piscivores (12)	L/NC	L/NC	NC/NC	NC/NC	NC/NC	NC/NC	NC/NC	U/NC
Food availability (10)	L/H	L/H	H/H	H/H	H/H	H/H	H/H	H/H

FR—fishery removals
PO—pollution
CE—climate/regime shift
PRED—predation
DT—direct take (shooting)
SH—subsistence harvest
IT/ENT—incidental take/entanglement
D—disease

H—Higher
H*—Higher or no change
L—Lower
L*—Lower or no change
NC—No change
U—Uncertain

Response Variable Analysis

- Recent indicators of SSL health and foraging behavior suggest that the western population is not food limited when compared to the increasing population in Southeast Alaska
- The weight of recent evidence for causality is most consistent with top-down forcing mechanisms

Conclusions for 1970s-1980s

- 5-year period of rapid decline was broad, likely caused by an ecosystem-wide change. Consistent hypotheses are:
  - nutritional limitation by fisheries competition
  - nutritional limitation by regime shift of late 1970s
  - predator switching from depleted prey to SSLs
  - introduction of highly contagious disease
- Evidence for nutritional limitation: SSL condition, growth, and reproductive performance were low, but ecosystem models imply prey abundance cannot explain full decline
- No systematic data on killer whale or shark predation
- Serological tests for common pathogens are negative
- Subsistence harvests, toxic algal blooms, and illegal shooting likely vary by area and no evidence of large increase during 5-year period

Conclusions for 1970s-1980s

Photo: Bill Rawlins

Photo: Oceanic Research Foundation

Photo: Betty Sederquist http://www.sederquist.com

Photo: NOAA, Alaska Fishery Science Center

→ **Multiple factors likely contributed to widespread declines in the 1980s, including mortality associated with fishing**

Conclusions for 1990s-Present

- Groundfish biomass during the 1990s is large relative to SSL abundance, but localized depletion may occur
- Although limited in scope, recent measurements of SSL condition and foraging activity indicate that bottom-up hypotheses invoking nutritional stress are unlikely to represent the primary threat to recovery
- A combination of top-down mortality sources seem to pose the greatest threat to the current population:
    - Predation
    - Illegal shooting
    - Incidental take by fishing
    - Subsistence harvest

Information Gaps/Research Needs

<u>Population trends:</u> continue aerial surveys of juveniles and adults and directs counts of pups at selected rookeries

<u>Vital rates:</u> fecundity, age of 1st reproduction, age distribution, juvenile and adult survival, and growth rates using:

- Reproductive data from cooperative programs with subsistence hunters
- Other parameters from branding/resighting program over lifespan of SSL

<u>Critical habitat:</u>

- Stomach telemetry tags to associate at-sea location with feeding
- Fishing effects on fish distributions and densities
- Revisit critical habitat designations

Information Gaps/Research Needs (con't.)

Environmental monitoring:

- Oceanographic conditions
- Plankton composition, harmful algal blooms
- Forage fish, cephalopods, arrowtooth flounder
- Seasonal migrations of groundfish
- Sampling of SSLs for disease agents

Predator feeding habits and population size:

- Killer whale diet, population size and distribution
- Observer programs to record killer whale feeding
- Salmon and sleeper shark abundance and diet

Information Gaps/Research Needs (con't.)

Other considerations:

- Most studies in summer, but increased SSL mortality may occur in other seasons
- Fate of juveniles remains a potentially pivotal question
- Remote observation methods (satellite, video) needed to assess seasonal activity patterns
- Conclusive results on many variables critical to fishery management will take 5-10 yr to collect
- A prioritized, cohesive research plan is needed to address these information needs

What monitoring program is needed to evaluate efficacy of management approaches?

- Although most evidence indicates that groundfish fisheries are not causing range-wide depletion of SSL food resources, there is insufficient evidence to fully exclude fisheries as a contributing factor to the continuing decline owing to potential:
  - Localized depletion
  - Incidental mortality from entanglement
  - Disturbance of animals on haulouts
  - Increased exposure to predators by attraction to fish catches
  - Continued illegal shooting
- Fisheries are one of the few human influences in SSL environment, and are subject to regulation under ESA

Monitoring to Evaluate Management Efficacy

The committee evaluated **5 management options** with respect to their scientific potential to discern the role of the groundfish fishery in the SSL decline:

- **Wait and see, maintain current closures indefinitely.** Perhaps recent management actions will work.
  - ➔ The most valuable monitoring information would be derived from annual rookery/haulout counts and new demographic data from branded pups.
- **Eliminate direct fishery impacts from greatly expanded closures.** For instance, close Atka mackerel fishery and main pollock areas in southern half of EBS.
  - ➔ Monitoring of fish population dynamics, both locally and at stock level, is required to determine effects of fisheries on stock distribution and fish community composition.

Monitoring for Management Efficacy (con't.)

- Establish spatial management units consisting of two sets of closed and open areas where each treatment area is centered on a rookery. The western stock is divided into management regions with at least two closed and two open rookeries per region. "Closed" units are subject to fishery closures and "open" units have SSL-related restrictions removed.
  - ➔ The most critical monitoring needs are detailed SSL censuses and spatial analyses of fish population change for each experimental unit.
- Implement a "titration experiment" where restrictions are increased until a positive response is achieved.
  - ➔ Monitoring of SSL trends, but results could be confounded by lack of baseline data and natural environmental variability.

Monitoring for Management Efficacy (con't.)

- **Micro-monitor and manage localized interactions between SSLs and fisheries to reduce mortality when and where it occurs in the future.** The expense of this program is high because it requires year-round monitoring to detect mortality events in all areas.
  - → All basic monitoring activities (e.g., abundance, prey fields, mortality agents) must be expanded around key rookeries to pinpoint times and places of increased mortality so that appropriate management measures could be taken.

Preferred Option #3

Option 3 is preferred because it is:

- the only approach that directly tests the role of fishing in the decline
- an adaptive management experiment, which reduces the possibility that regulation of the fishing industry is perpetuated without demonstrable benefit to SSLs
- placement of open areas in historical areas of high effort decreases negative impacts on fisheries
- provides contrasting treatments for valid comparisons; open areas restore opportunities for fisheries, whereas closed areas remove potential negative effects of fisheries on SSLs
- controls for common effects, such as large-scale changes in oceanographic regimes

Guidelines for Spatial Units Under Option 3

- **Fished area.** Design closures to minimize displacement of fisheries to more distant, less safe areas. Two experimental treatment options:
  - **Close groundfish fisheries only** – a positive response implicates groundfish fisheries
  - **Close all fishing** – a positive response implicates fishing. Closure to all fishing provides greatest contrast.
- **Size and number of treatment areas.** Size depends on fish and SSL movements; radius ~20-50 nm. Replicates are needed to assess environmental variability.
- **Timescale.** Some data gaps can be filled in <5 yr (e.g., evidence of disease, localized depletion, improved mortality estimates), but 5-10 yr required to assess recruitment and mortality rates

Final Conclusions

- Western stock of SSLs declined >80% since the 1970s with a spatial and temporal pattern
- Evaluation of hypotheses suggests that:
  - Multiple factors probably contributed to the decline in the 1980s, including incidental and deliberate mortality associated with fishing activities
  - Although no hypothesis can be excluded based on existing data, top-down sources of mortality appear to pose the greatest threat to the current population
- Critical information gaps and research and monitoring priorities were identified
- A spatially explicit management experiment is proposed to test the role of fishing in the decline